AD-A073 080   AIR FORCE GEOPHYSICS LAB HANSCOM AFB MA   F/G 8/14
               CORRELATION STUDIES OF PROTONOSPHERIC ELECTRON CONTENT OVER THE--ETC(U)
               MAR 79   A SHUVAL, J A KLOBUCHAR, H SOICHER
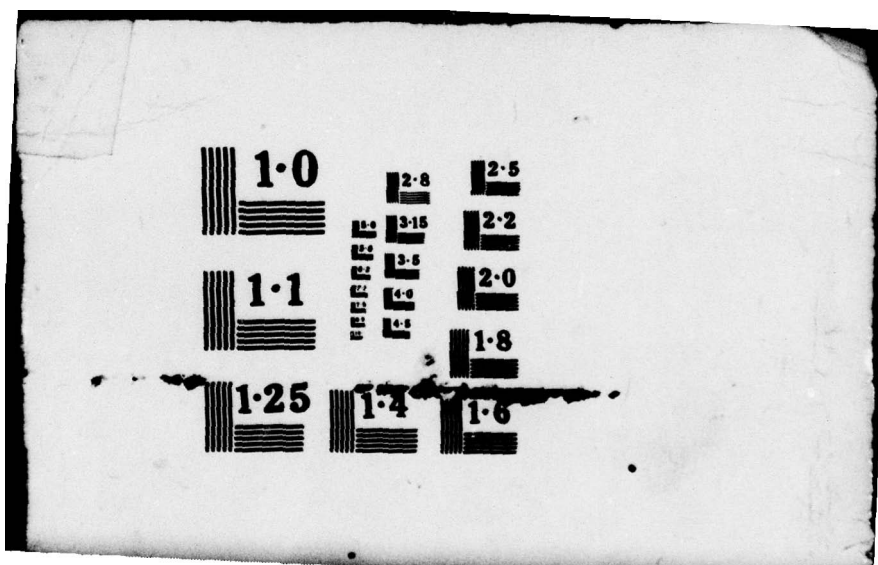UNCLASSIFIED   AFGL-TR-79-0064   NL

1 OF 1
AD
A073080

END
DATE
FILMED
9   79
DDC

1·0

1·1

1·25

2·8

3·15

3·5

1·4

2·5

2·2

2·0

1·8

1·6

AFGL-TR-79-0064
ENVIRONMENTAL RESEARCH PAPERS, NO. 663

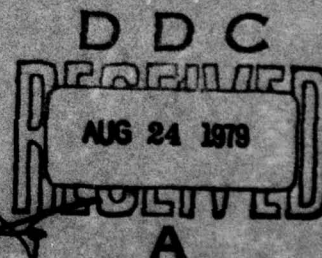# Correlation Studies of Protonospheric Electron Content Over the U. S. Continent

A. SHUVAL
J. A. KLOBUCHAR
H. SOICHER

6 March 1979

LEVEL

DDC
RECEIVED
AUG 24 1979
A

SPACE PHYSICS DIVISION   PROJECT 4643
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

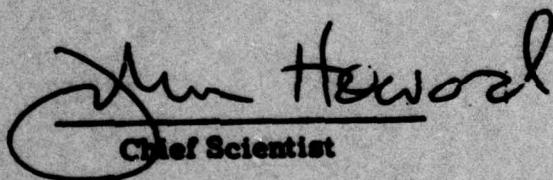AIR FORCE SYSTEMS COMMAND, USAF

DDC FILE COPY

AD A073080

79 08 24 003

This report has been reviewed by the ESD Information Office (OI) and is releasable to the National Technical Information Service (NTIS).

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Chief Scientist

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-79-0064 **2. GOVT ACCESSION NO.** AFGL-ERP-658	**3. RECIPIENT'S CATALOG NUMBER**
4. TITLE *(and Subtitle)* CORRELATION STUDIES OF PROTONOSPHERIC ELECTRON CONTENT OVER THE U.S. CONTINENT.	**5. TYPE OF REPORT & PERIOD COVERED** Scientific. Interim.
	6. PERFORMING ORG. REPORT NUMBER ERP No. 658
7. AUTHOR(s) A. Shuval J. A. Klobuchar H. Soicher	**8. CONTRACT OR GRANT NUMBER(s)**
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (PHP) Hanscom AFB Massachusetts 01731	**10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS** 062101F 46430464
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (PHP) Hanscom AFB Massachusetts 01731	**12. REPORT DATE** 6 March 1979
	13. NUMBER OF PAGES 26
14. MONITORING AGENCY NAME & ADDRESS *(if different from Controlling Office)*	**15. SECURITY CLASS.** *(of this report)* Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

Environmental research papers,

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES *Emmanuel College, Boston, MA 02115; on sabbatical leave from the National Committee for Space Research, Haifa Radio Observatory, P.O.B. 4655, Haifa, Israel.
**Communications Systems Center, U.S. Army Communications Research and Development Command, Fort Monmouth, NJ 07703.

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*
Protonospheric electron content
Faraday rotation
Group path delay
ATS-6 protonospheric measurements

N sub p

N sub p

N sub p

CONT

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Measurements of the electron content of the earth's protonosphere, N_p, defined here as the region above the height where Faraday rotation measurements of VHF signals are significant, have been compared from pairs of stations in North America. Results of studies of N_p and of the variabilities from the monthly mean values at station pairs show a lower correlation than expected. Correlation coefficients of total electron content data taken at the same station pairs by the group-delay technique and by the Faraday rotation technique are significantly higher than those from N_p data. The random

DD FORM 1 JAN 73 **1473** EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE *(When Data Entered)*

N sub P

20.   (Cont)

CONT

component necessary to explain the lower than expected correlation of N_p values is larger than the estimated data accuracy from the stations.   From the available data we are unable to conclude whether or not the lower than expected correlation coefficients represent a real random component in the protonosphere having horizontal scale sizes less than 400 km.

Preface

We would like to thank Dr. L. Kersley from the University College of Wales, Aberysteryth, Wales, for many helpful discussions in the course of this work.

3

Contents

Illustrations

Correlation Studies of Protonospheric Electron
Content Over the U.S. Continent

1. INTRODUCTION

Continuous measurements of the electron content of the earth's protonosphere, here defined as the region above the height where Faraday rotation measurements of VHF signals transmitted from geostationary satellites are significant, have only been possible since mid-1974 with the launch of an ionospheric beacon transmitter on the NASA Applications Technology (ATS-6) satellite. The protonospheric electron content, N_p, is obtained by taking the difference between the total electron content, N_T, along the entire satellite to ground station path, as measured by the group-path delay of 1 MHz modulation envelopes on RF carriers at 140 and 360 MHz, and the electron content, called N_F, inferred from the Faraday rotation along the same path.

A description of the experimental technique has been given by Davies et al.[1] and papers illustrating the monthly mean or median behavior of N_p have been published by Soicher,[2] Davies et al,[3] and Klobuchar et al;[4] changes in N_p during individual magnetic storms have been described by Soicher,[5] Davies et al,[1] Kersley et al,[6] Degenhart et al,[7] and Poletti-Liuzzi et al.[8] Klobuchar and Johanson[9] presented a comparison of monthly average N_p from two U.S. stations, Kersley and Klobuchar[10] compared average protonospheric electron content from the

7

American and European sectors, and Kersley and Klobuchar[11] looked at the average response of N_p to geomagnetic storms. This report is a first attempt to determine correlations of day-to-day behavior of N_p at pairs of stations in North America and compare them with correlations of values of N_F, the corresponding ionospheric electron content obtained from the well known Faraday rotation technique.

2. EXPECTED RESULTS

Studies of the correlation distance of the F2 region have been done using the f_oF_2 parameter by Rush[12] and using the TEC parameter, actually N_F, by Klobuchar and Johanson.[13] Since N_F is greatly weighted by electrons near h_{max}, the good agreement between the correlation distances obtained by Rush and Klobuchar and Johanson with the two parameters was expected. The correlation distance, defined as that distance where the correlation coefficient falls to 0.7, is approximately 2000 to 3000 km for mid-latitude stations separated in longitude, and approximately 1000 to 2000 km of latitude for stations at the approximate same longitude. These results apply to the U.S. region.

The competing processes of production, loss, and movement of ionization that must be due to such factors as changes in solar EUV, molecular to atomic neutral species ratio, neutral wind velocity, and electric fields are responsible for the approximate 25 percent day-to-day variability that, of course, reduces the correlation of the measured quantities. In the case of the protonospheric electron content, which in the present study was obtained from three U.S. stations—Hamilton, Massachusetts (42.6°N, 70.8°W), Fort Monmouth, New Jersey (40.18°N, 74.06°W), and Boulder, Colorado (40.13°N, 105.24°W)—our initial expectations were that the correlation distance would be at least as large, and probably greater, than that of the density near the peak of the F2 region, as manifested by f_oF_2 and N_F.

Evans and Holt[14] have shown that the H^+ flux into the northern mid-latitude protonosphere is near the limiting value in the daytime nearly all the time, and one would expect that the only significant loss would occur during magnetic storms. This loss should be generally well correlated over relatively large geographic regions,

11. Kersley, L., and Klobuchar, J.A. (1979) Storm associated protonospheric depletion and replenishment, to be published.

12. Rush, C.M. (1976) An ionospheric observation network for use in short term propagation predictions, Telecommunication Journal, 43(No. 8):544-549.

13. Klobuchar, J.A., and Johanson, J.M. (1977) Correlation Distance of Mean Daytime Electron Content, AFGL-TR-77-0185, ADA048117.

14. Evans, J.V., and Holt, J.M. (1978) Nighttime proton fluxes at Millstone Hill, Planet Spac Sci. 26:727-744.

at least within the northern U.S. sector. In the absence of significant electric fields in the protonosphere, the changes in the observed values of N_p can only be due to ionization flow along field lines to and from the local and the conjugate ionospheres.

The ray paths from the three stations to the ATS-6 satellite cross many magnetic field lines; we have designated them by their equivalent L shells, the distance in earth radii that an individual field line would be from the earth's center when above the magnetic equator. Though the ray paths from these stations to the ATS-6 satellite cross field lines from an L shell corresponding to a height of 2500 km at the base of the protonosphere to the height of the satellite, most of the columnar content in N_p lies near the base of the protonospheric path crossed by the straight line from the ground station to the satellite, that is, at heights just above 2500 km. The ray path reaches a minimum L value of approximately 2 near the base of the protonosphere, and the electron density along any field line is assumed to be in diffusive equilibrium along the field line, with greatest density at the base of each field line. Consequently, the greatest contribution to N_p, as measured by this technique where many field lines are crossed by the ray path to ATS-6, is near the base of the protonospheric portion of the ray path.

The source region for the protonospheric ionization lies potentially in both the local and the conjugate ionospheres, probably maximizing at a height of approximately 350 km where production is maximum. Therefore, we have traced the field lines down to their 350-km height point at both the local and the southern conjugate regions, and have illustrated these regions in Figure 1. Note from Figure 1 that, since only one field line crosses the location of the ATS-6 satellite, this line maps down to only one point in each hemisphere.

As the height along the ray path from the satellite to the different stations decreases, the base of the magnetic field lines at 350 km from the three stations separates, but is generally closer than the actual 350-km intersections also used as the reference height for the Faraday rotation measurement of N_F. Distances between the mean ionospheric height of 350 km (looking towards ATS-6 from the stations) and the mean protonospheric height of 3000 km (probably within a scale height or two of the base of the mean protonosphere) are given in Table 1.

From Table 1 it can be seen that the distance between the ionospheric and plasmapheric points of Hamilton and Ft. Monmouth is about 15 percent of the comparable distance between the other station pairs; hence, it is expected that the ionospheric and protonospheric electron contents between the Hamilton and Ft. Monmouth stations should give much higher correlation than the correlation between the Hamilton and Boulder or the Ft. Monmouth and Boulder station pairs.
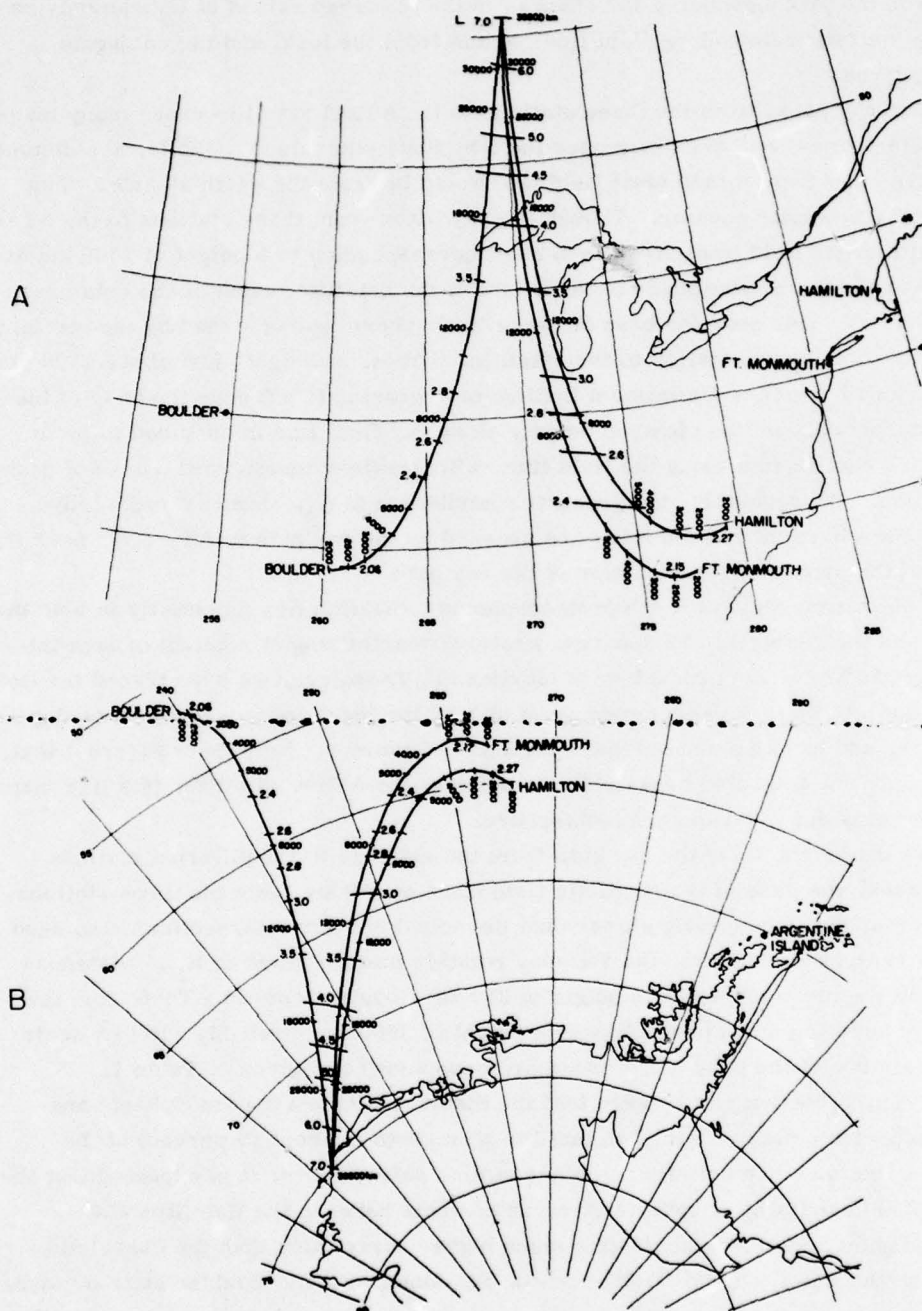
9

Figure 1. Projection of Magnetic Field Lines From Ray Paths to ATS-6 Down to a Height of 350 km in Both Local and Conjugate Hemispheres

10

Table 1. Distance Between Mean Ionospheric and Protonospheric Heights for Hamilton, Ft. Monmouth, and Boulder

Station Pair	Ionospheric Distance (350 km ht) (km)	Protonospheric Distance (3000 km ht) (km)
Hamilton-Ft. Monmouth	375	393
Hamilton-Boulder	2830	2525
Ft. Monmouth-Boulder	2602	2305

3. EXPERIMENTAL DATA

For the first year of its operation, the ATS-6 satellite was located at 94°W longitude, thus enabling observations to be made by several U.S. experimenters. To test our N_p correlation hypothesis, we obtained N_p values from the only three U.S. stations that are known to have reduced all the data from the first year of operation of ATS-6. Table 2 lists the geographic locations of these stations and the coordinates of the intersections between the ray paths (from the stations to the satellite) and the ionosphere at 350 km height.

Table 2. Location of Stations From Which Data Were Used in Correlation Study, and Their Respective Mean Ionospheric Points (looking towards ATS-6)

Station	Geographic Coord. of Stations		Coord. of Mean Iono. Points at 350 km	
Hamilton	42.6 °N,	70.8 °W	39.03°N,	73.55°W
Ft. Monmouth	40.18°N,	74.06°W	36.72°N,	76.34°W
Boulder	40.13°N,	105.24°W	36.67°N,	104.03°W

Values of N_p were obtained by finding the differences between two carefully calibrated experimental quantities, N_T minus N_F. The determination of N_F from measured values of Faraday along the path from the ground observer to the satellite was considered by Davies et al[1] and by Polletti-Liuzzi,[8] so we will not discuss it here. The measurement of N_T, the group-path delay of 1 MHz modulation evelopes on RF carriers at 140 and 360 MHz, is straightforward in the sense that there is no geometric effect to influence the results. It should be noted, however, that carefully calibrated experimental values of both N_T and an equivalent N_F are a prerequisite to obtaining their difference, N_p, since at most times N_T and N_F are

11

within a few percent of each other. From the Hamilton and Ft. Monmouth stations, smoothed hourly values of N_p were obtained by forming the average of five values taken at 15-min intervals, centered on the hour. For Boulder, data were taken from published results.[15] These are actual hourly values with no smoothing.[16]

4. EXPERIMENTAL RESULTS

4.1 Monthly Mean Values of N_p

Plots of mean monthly values of N_p vs local time are shown in Figure 2. The first important feature that can be seen in Figure 2 is that the N_p curves show a midday minimum and a nighttime maximum, especially from November onwards. This is in agreement with previously published results[10] and stems largely from the fact, pointed out by Kersley and Klobuchar,[10] that the flux tubes within the protonosphere may be regarded as closed systems interacting with the ionosphere in both local and conjugate hemispheres. Thus, the conjugate ionosphere at high geographic latitude, which is completely lit during northern hemisphere winter and has a maximum of ionization occurring around local midnight, contributes large quantities of electrons in such a manner as to negate and overcome the effects in the local hemisphere that usually tend to create a midday maximum and nighttime minimum.

The other main feature in Figure 2 is that generally the Hamilton values are the lowest in absolute value. Lower absolute values of N_p from Hamilton do agree with the fact that the minimum L shell value encountered on the ray path from ATS-6 to the three ground stations is greatest for the Hamilton station, as can be seen in Figure 1. The absolute values of the Hamilton data for the months of September and October 1974 should be treated with caution, due to equipment calibration problems that occurred during those months.

At first glance the general diurnal shape of the N_p curves for the three stations seems to be similar, but by taking the correlation between the 24 monthly mean values, one for each hour, any differences in diurnal shape can be easily seen, with differences in average levels or any bias errors not contributing to the correlation coefficient.

---

15. Fritz, R. B. (1976) ATS-6 Radio Beacon Electron Content Measurements at Boulder, July 1974 — May 1975, Report-UAG 58, World Data Center A, September.

16. Fritz, R. B. (1978) Private communication, August 1978.

Figure 2.   Monthly Average Values of N_p vs Local
Time for Hamilton, Ft. Monmouth, and Boulder

Figure 3 shows the correlation coefficient, r, between the mean monthly curves
for Hamilton and Ft. Monmouth and for Hamilton and Boulder for the 10 months of
available data.   The error bars represent 95 percent confidence limits, assuming
a Gaussian distribution of values about the mean.   The surprising fact in Figure 3
is that the correlation of the monthly average values of N_p between Hamilton and
Boulder is higher than that between Hamilton and Ft. Monmouth, in particular for
the equinox and winter months.   This is in contrast to our expectations.   The differ-
ences in the correlations of the monthly average N_p data can be inferred directly
from the curves.   For example, it can easily be seen in Figure 2 that in November
1974 the Hamilton and Boulder curves have similar diurnal shape, whereas the
Ft. Monmouth diurnal curve departs strongly from that pattern.   This point will
be discussed later.

13

Figure 3. Correlation Coefficient, r, Between the
Mean Monthly Curves of N_p for the Station Pairs
Indicated for the Period August 1974 Through May
1975

4.2 Correlation of N_p Values Between Station Pairs
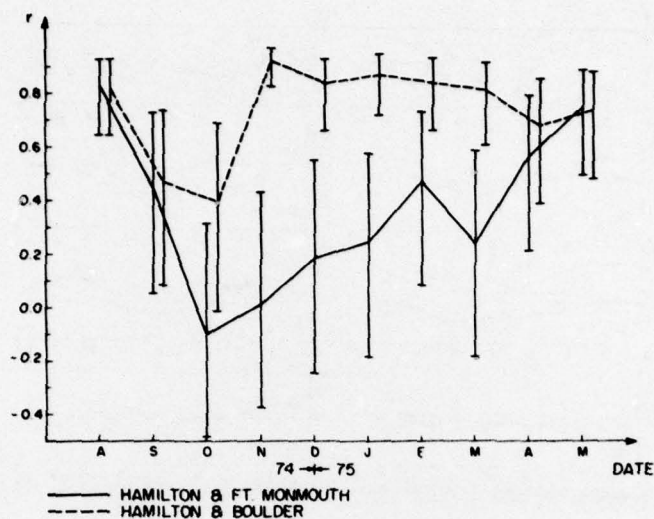
Using the smoothed hourly values of N_p from the Hamilton and Ft. Monmouth
stations and the available actual hourly values from Boulder, correlation coefficients
were calculated for each month for pairs of values over three different time inter-
vals: 10 to 16 LT, 00 to 04 LT, and 00 to 24 LT at each station. In addition to cal-
culating the correlation coefficients between the smoothed hourly N_p values, corre-
lation coefficients were calculated for the variability remaining at each hour when
the monthly mean value for each hour was subtracted. For the variabilities, cor-
relation coefficients were calculated for the same time intervals. By calculating
r for the variabilities from the monthly mean, rather than for the actual values,
any possible influence of the different diurnal shapes of the monthly mean values at
pairs of stations is eliminated. Figure 4 illustrates the correlation coefficients
between pairs of stations for the actual values of N_p and for their variability from
monthly mean hourly values for the time periods of 00 to 04 LT, 10 to 16 LT, and
00 to 24 LT. As in Figure 3 the error bars represent the 95 percent confidence
limits, assuming a Gaussian shape of differences about the mean values.

Looking at the 10 to 16 LT and the 00 to 04 LT curves in Figure 4, it can be
seen that no significant differences in the day or nighttime behavior of correlation
coefficient r exist. Further, it cannot be said with any degree of certainty that r is

14

greater between any one pair of stations, because the error bars overlap. For the full 24-hr correlation, there are three distinct months in which the correlation between Hamilton and Boulder is higher than that between Hamilton and Ft. Monmouth—November, January, and March.

Figure 4. Correlation Coefficient, r, Between (A) Smoothed Hourly Values of N_p and (B) the Variability Remaining After Subtracting the Monthly Average Values of N_p for the Station Pairs and Local Time Periods Indicated for the Months August 1974 Through May 1975

It should be noted, however, that there is a different pattern in the case of the correlation of the variabilities for the 24 hourly values shown in Figure 4. This correlation behaves much more like we expected from the correlation of the N_p hourly values themselves, that is, there are three distinct months—September, December, and February—in which the Hamilton-Ft. Monmouth pair give higher r

15

values than the Hamilton-Boulder pair (it should be kept in mind though that the
Hamilton data for September 1975 is of lower quality, due to calibration problems
mentioned earlier).

A comparison of the 24-hr correlation coefficients shown in Figure 4 shows the
influence that the different diurnal shapes have on the result; that influence is
removed when only the variabilities are correlated.

4.3 Correlation of N_T and N_F for Station Pairs

In an attempt to determine what might account for the lower values of r for N_p
values taken for the Hamilton-Ft. Monmouth station pair, cross correlation coef-
ficients were calculated for the parameters N_T and N_F for the same time periods
as for the N_p data.

Figure 5 shows the results of these correlations for N_T. It can be clearly
seen that in almost every case the correlation between Hamilton and Ft. Monmouth
is higher than the correlation between Hamilton and Boulder. The one exception is
October for the nighttime period. As was mentioned earlier, the data taken at
Hamilton during that month was of doubtful calibration and, therefore, this excep-
tion is disregarded.

Looking at the results for the 24-hr period, it is interesting to note that corre-
lation between the variabilities between Hamilton and Ft. Monmouth is almost the
same as the correlation of the hourly values themselves. This is not the case be-
tween Hamilton and Boulder, where the correlation of the variabilities drops sig-
nificantly below that of the hourly values, again due to the removal of the pre-
dominant 24-hr term. The N_T values are so highly correlated between the Hamilton
and Ft. Monmouth stations that their correlation is not significantly affected by the
removal of the 24-hr term. On the other hand, the high correlation of the hourly
values with Boulder depend strongly upon the 24-hr term. [17]

The results of the correlation of values of N_F between pairs of stations are
similar to those of N_T and are shown in Figure 6. The only difference is that in
this case there is no exceptional month in which the r value is greater for the station
pair with greater separation, as there was during the nighttime period for the month
of October 1974. This confirms the calibration difficulty with the group-delay
receiver at the Hamilton station during that month.

The fact that values of both N_F and N_T are correlated as expected for the two
station spacings is encouraging, but still does not remove the suspicion of errors
in the N_p parameter, which is a much smaller quantity than either N_T or N_F. Small
errors in N_T and N_F, which will hardly affect the correlation of these quantities,

17. Soicher, H. (1978) Spatial correlation of transionospheric signal time delays,
    IEEE Transactions on Antennas and Propagation, AP-26(No. 2):311-314.

may still strongly influence the correlation of N_p. According to our a-priori expectations, the correlation between N_p values at the Hamilton and Ft. Monmouth station should be very high, say approximately 0.9 or greater, but in Figure 4 it can be seen that the actual correlation is approximately 0.6, presumably due to random errors that occur at both stations.

As a further check on the validity of the results of these cross correlations of N_p values between station pairs, we used the two months of N_p data from the Bozeman, Montana, and the Dallas, Texas, stations available from Davies et al[18]. The distances between the mean ionospheric and protonospheric points for these station pairs, including Boulder, Colorado, are given in Table 3.

Figure 5. Correlation Coefficient, r, Between (A) Hourly Values of N_T and (B) the Variability Remaining After Subtracting the Monthly Average Values of N_T for the Station Pairs and Local Time Periods Indicated for the Months August 1974 Through May 1975

18. Davies, K., Degenhardt, W., Hartmann, G.K., and Leitinger, R. (1977) Electron Content Measurements Over the US, Joint Radio Beacon Program NOAA/MPA/GRAZ Station Report, ATS-6, 94°W., Edited by Max-Planck Institute for Aeronomie.

00-04 HOURS LT (A)

00-04 HOURS LT (B)

10-16 HOURS LT (A)

10-16 HOURS LT (B)

00-24 HOURS LT (A)

00-24 HOURS LT (B)

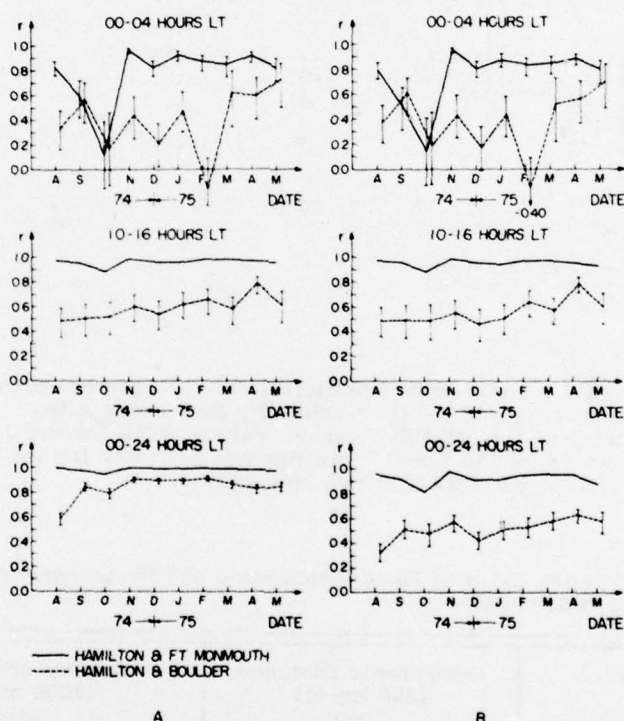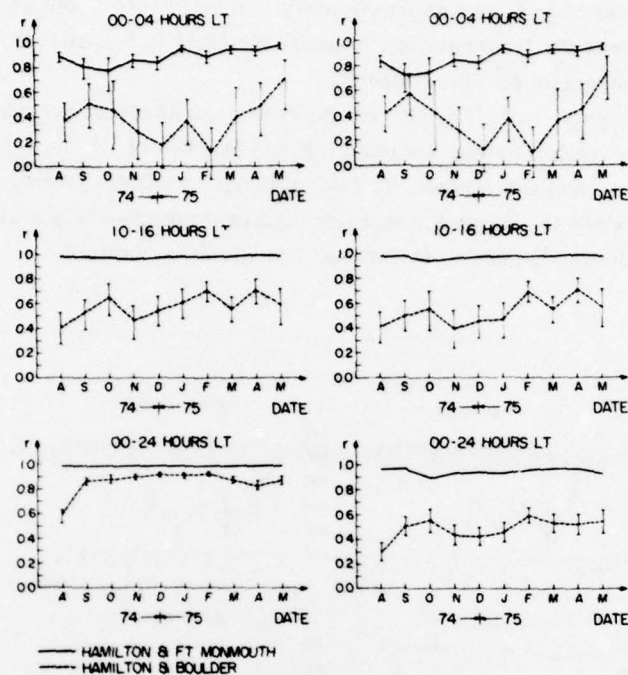—— HAMILTON & FT MONMOUTH
---- HAMILTON & BOULDER

A   B

Figure 6. Correlation Coefficient, r, Between (A) Hourly Values of N_F and (B) the Variability Remaining After Subtracting the Monthly Average Values of N_F for the Station Pairs and Local Time Periods Indicated for the Months August 1974 Through May 1975

Table 3. Distance Between Mean Ionospheric and Protonospheric Heights for Indicated Station Pairs

Station Pair	Ionospheric Distance (350 km ht) (km)	Protonospheric Distance (3000 km ht) (km)
Bozeman-Boulder	717	532
Boulder-Dallas	1048	867
Dallas-Bozeman	1757	1394

The distance between the closest pair of stations in Table 3, namely Boulder and Bozeman, is greater than the distance between the Hamilton-Ft. Monmouth station

18

pair, though still much less than the distance between either east coast station from Boulder. The variability of the individual values of N_p from the monthly mean values for each hour are given in Figure 7 for the months of August and December for these station pairs. In addition, the correlation between N_p values from the closely spaced Hamilton-Ft. Monmouth station pair is shown again for reference. Note that there are few significant differences between the correlation results for any of these station spacings, indicating that the nature of a significant portion of the day-to-day variability of N_p values is apparently random.
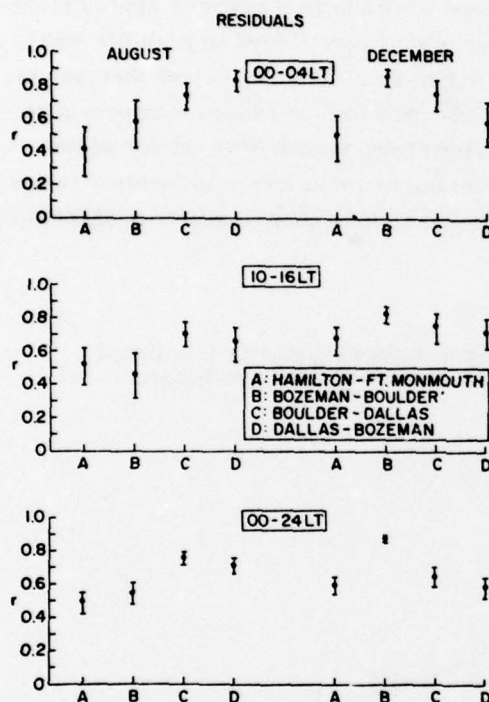

Figure 7. Correlation Coefficient, r, Between the Variability Remaining After Subtracting the Monthly Average Values of N_p for the Months of August and December 1974 for the Time Periods and Station Pairs Indicated

5. RANDOM ERROR SIMULATION

If random errors are really the main cause of the reduction in correlation between N_p values at closely spaced stations, it is of interest to have estimates of their magnitude. The easiest way to estimate the magnitude of the random errors is by computer simulation. This was done by taking an N_p data file and correlating it against itself, after adding two different, progressively greater, random noise components in the cross correlation calculation.

A random function generator was used to generate a random number uniformly distributed in the interval -1 to +1. The value of protonospheric electron content

19

N_{PL} was calculated from the original value N_p using the relationship

$$N_{PL} = N_p + K \times RANF \quad (TEC\ units^*)$$

where RANF is the random number generator and K is a varying factor multiplying the RANF function that determines the maximum amplitude of the random errors.

Figure 8 shows the results of this calculation. As expected, the correlation decreases with increasing noise introduced in the data. The amount of random error is shown in two scales; the upper one is a multiplying factor K and the lower one is the rms error. A correlation of 0.6 is reached when the rms error is approximately 0.7 TEC unit, that is, when the random error rms level added to each file was 0.7 TEC unit. This is in comparison to the actual rms of the N_p values themselves, which is 2.03 TEC units. This value of 0.7 TEC unit for the random component of N_p is greater than the estimated errors in determining values of N_p at any of the three stations. For the Hamilton station the estimated rms error in forming values of N_p is less than 0.5 TEC unit. For Ft. Monmouth it is approximately 0.25 TEC unit, and for Boulder even smaller. [4]

CORRELATION COEFFICIENT OF BOULDER Np HOURLY VALUES FILE-WITH ITSELF,
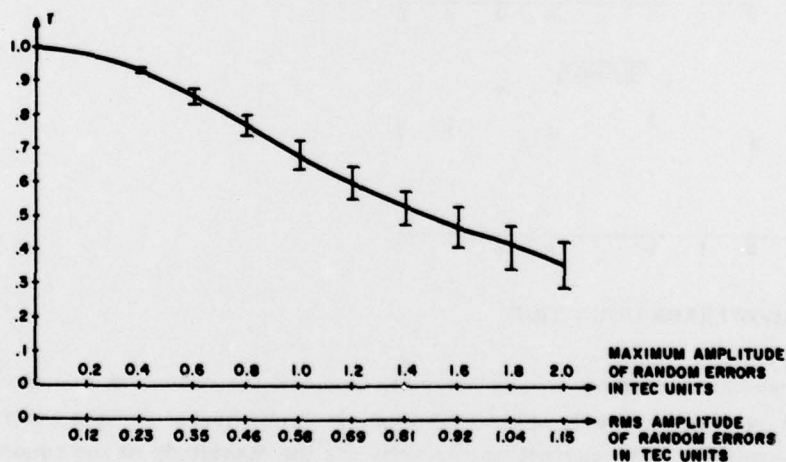AS FUNCTION OF SIMULATED RANDOM ERROR INTRODUCED INTO THE DATA

Figure 8. Correlation Coefficient of N_p Values as a Function of Simulated Random Errors Introduced Into the Data

---

*One TEC unit equals 1×10^{16} eℓ /m^2 column.

20

It should be kept in mind, though, that the TEC errors given above refer to random errors, mainly readings from recorder charts, etc., and do not include other sources of error such as the change of F_L with height mentioned by Davies et al. [1] Changes in F_L, of course, influence the diurnal pattern of N_p, but, since Hamilton and Ft. Monmouth are so near to each other, the F_L changes will be very similar at both stations and, thus, will not affect the correlation of N_p values. Based on these estimates, the 0.7 TEC unit rms random error due to equipment and mean ionospheric variability seems to be large.

6. CORRELATION OF FT. MONMOUTH vs BOULDER

Since all the correlations were calculated using Hamilton as the reference data set, it is of interest to see if there is a different pattern of behavior using Ft. Monmouth as the reference data set. Figure 9 shows the results of the correlation of N_p hourly values and also their variabilities for the whole day between Ft. Monmouth and Hamilton and also between Ft. Monmouth and Boulder. Generally, the curves in Figure 9 do not differ considerably; all the error bars overlap, with the exception of August and December. Again the figure does not show the expected results, namely a higher correlation between Ft. Monmouth and Hamilton than that between Ft. Monmouth and Boulder. Comparing Figure 9 to Figure 4 reveals that the whole-day hourly values behave in a different manner. The correlation between Ft. Monmouth and Boulder in Figure 9 is significantly lower than that between Hamilton and Boulder, as shown in Figure 4 for the months of November, December, January, and March.

The situation is shown in a more dramatic way by contrasting the content of Figure 10, which shows the correlation of the mean monthly curves using Ft. Monmouth as a reference point, to Figure 3. In Figure 10 the correlation with Boulder, the distant station, seems to be comparable to the correlation with the close station, whereas in Figure 3, the correlation with Boulder seems to be significantly higher. This is very puzzling for two reasons: First, if random errors are the main cause of the reduction of correlation between Hamilton and Ft. Monmouth, then how is it that in the mean curves, where the influence of these random errors is smaller, the correlation of the monthly average shape of the curves is not higher? Secondly, what kind of mechanism or process in the protonosphere can cause high correlation between Hamilton and Boulder and at the same time make the correlation between Ft. Monmouth and Boulder no higher when Hamilton and Ft. Monmouth are so close to each other?
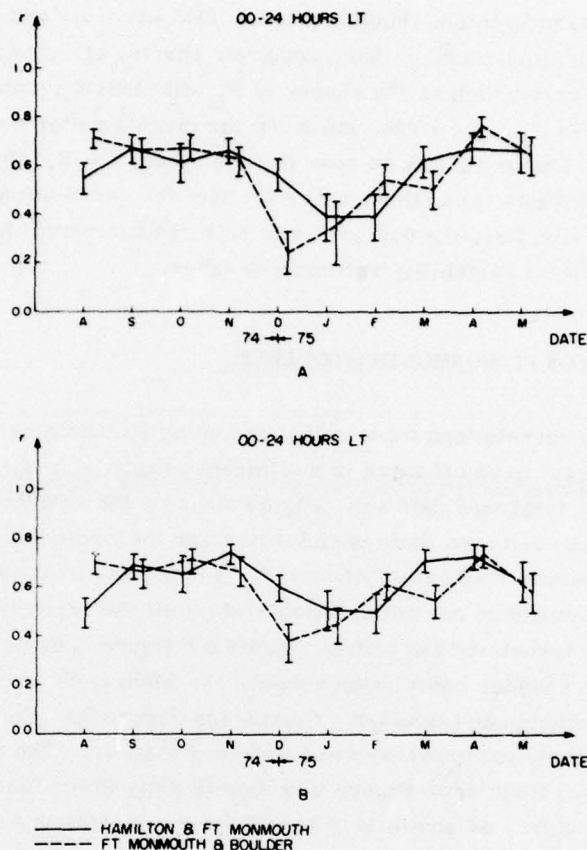
21

Figure 9. Correlation Coefficient, r, Between (A)
Hourly Values of N_p and (B) the Variability Remain-
ing After Subtracting the Monthly Average Values of
N_p for the Station Pairs Indicated for the Months
August 1974 Through May 1975

7. DISCUSSION

Our basic assumption in this study was that the flux tubes within the protonos-
phere represent closed systems interacting with the ionosphere in both local and
conjugate hemispheres. Therefore, the geographic locations at the height of peak
ionization production of the terminations of the geomagnetic field lines that intersect
the ray paths from the satellite to the various stations can be regarded as actually
the sources and drains of protonospheric electron content. Since the geographic
locations of these sources for Hamilton and Ft. Monmouth are very close, it was
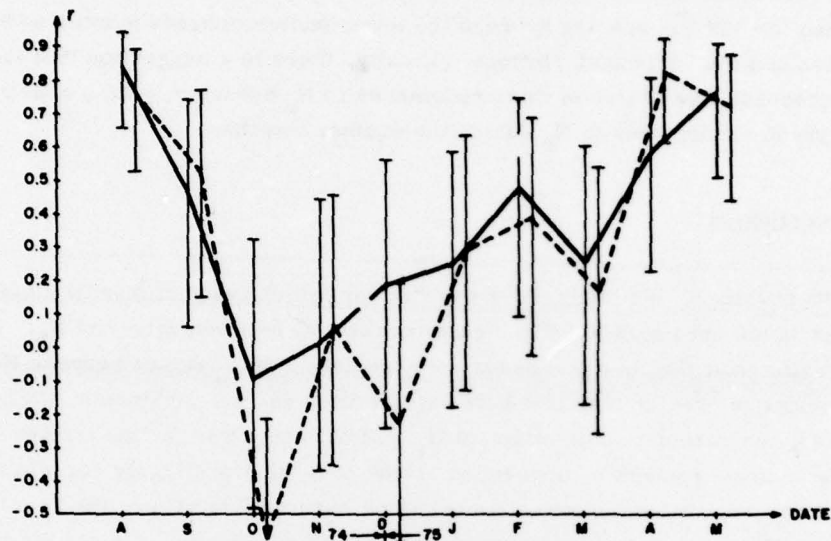
22

Figure 10. Correlation Coefficient, r, Between the Mean
Monthly Curves of N_p for Station Pairs Indicated for the
Period August 1974 Through May 1975

expected that the degree of correlation between the protonospheric electron content
measured at these stations would be significantly higher than the correlation between
N_p values from either of these stations and the N_p measured from Boulder. Our
results, however, do not show this behavior, and some months show even the oppo-
site, as can be seen from Figures 3 and 4.

In an attempt to explain this discrepancy, the first suspicion fell on the mea-
sured data itself. This is because N_p is a small quantity that is the difference be-
tween two larger ones, N_T and N_F, and is, therefore, more sensitive to measure-
ment errors of both N_T and N_F. We have shown that a random component in N_p of
approximately 0.7 TEC unit is required to explain the observed correlation coeffi-
cients, at least for the close station pair of Hamilton and Ft. Monmouth. This
magnitude of random error is greater than the random experimental error at either
station, and with the averaging that was done to the original data to obtain smoothed
hourly values of N_p, the random experimental error should be smaller than 0.7 TEC
unit.

23

If the observations are complete enough for the differences in the correlations presented here to be statistically significant, then we are faced with having to propose a random component in the protonosphere that has small scale size, certainly less than the 393-km spacing between the lower protonospheres monitored by the Hamilton and Ft. Monmouth stations. Finally, there is a suggestion that there is some seasonal dependence of this randomness in N_p behavior, with a seasonal minimum in randomness in N_p during the equinox months.

8. CONCLUSIONS

The results of this study did not verify our initial assumption that closer spaced stations would have significantly higher correlation between values of N_p. In fact, our results show that in a few cases the correlation of N_p values between Hamilton and Boulder is greater than that between Hamilton and Ft. Monmouth, while, as expected, the correlation of values of N_F and N_T are lower for the distant stations.

By adding a random component to values of N_p that are highly correlated, we can, of course, obtain the lower correlations observed; however, the rms magnitude of this random component is approximately one third the total value of the protonospheric electron content and higher than the estimated experimental errors. The slightly higher values of correlation between the variabilities of N_p from monthly average values for the full 24-hr interval seen for both station pairs in the equinox months, as compared with the winter season and perhaps the summer season, may mean simply that the random component is smaller during the equinoxes, the absolute values of N_p being approximately the same for all seasons, or even lower during the summer months.

The correlations of the values of N_T and N_F and that of their variability from the monthly mean values were as expected, namely greater correlation was observed for the closer station spacing. From the available data it was not possible to determine if the slightly higher correlation in the variability of N_p observed during the equinoxes was merely an artifact of the data or represents a real geophysical phenomenon. Data from other stations and a longer period of measurements would have greatly facilitated the making of this determination.

24

References

1. Davies, K., Fritz, R. B., Grubb, R. N., and Jones, J. E. (1975) Some early results from ATS-6 radio beacon experiment, Radio Science, 10(Nos. 8, 9):785-799.

2. Soicher, H. (1976) Comparative ionospheric and plasmaspheric electron contents from the three world regions, Nature, Lond., 264:46-48.

3. Davies, K., Fritz, R. B., and Gray, T. B. (1976) Measurement of the columnar electron content of the ionosphere and plasmasphere, J. Geoph. Res. 81(No. 16):2825-2834.

4. Klobuchar, J. A., Buonsanto, M. J., Mendillo, M. J., and Johanson, J. M. (1978) The contribution of the plasmasphere to total time delay, Proc. IES 78, Symposium on the Effects of the Ionosphere on Space and Terrestrial Systems, Washington, D. C., 24-26 January 1978.

5. Soicher, H. (1975) Response of electrons in the ionosphere and plasmasphere to magnetic storms, Nature, Lond., 253:252-254.

6. Kersley, L., Hosseinieh, H. H., and Edwards, K. J. (1978) Post magnetic storm protonospheric replenishment, Nature, Lond., 271:429-430.

7. Degenhart, W., Hartman, G. K., and Leitinger, R. (1977) Effects of magnetic storm on the plasmasphere, J. Atmos. Terr. Phys., 39:1435-1440.

8. Poletti-Liuzzi, D. A., Yeh, K. C., and Liu, C. H. (1977) Radio beacon studies of the plasmasphere, J. Geoph. Res., 82(No. 7):1106-1114.

9. Klobuchar, J. A., and Johanson, J. M. (1977) A Comparison of Average Plasmaspheric Content at Two Mid-Latitude Stations, paper presented at A.G.U. Spring Meeting, Washington, D. C., June 1977.

10. Kersley, L., and Klobuchar, J. A. (1978) Comparison of protonospheric electron content measurements from the American and European sectors, J. Geoph. Res., 5(No. 2):123-126.

11. Kersley, L., and Klobuchar, J. A. (1979) Storm associated protonospheric depletion and replenishment, to be published.

12. Rush, C. M. (1976) An ionospheric observation network for use in short term propagation predictions, Telecommunication Journal, 43(No. 8):544-549.

13. Klobuchar, J. A., and Johanson, J. M. (1977) Correlation Distance of Mean Daytime Electron Content, AFGL-TR-77-0185, AD A048117.

14. Evans, J. V., and Holt, J. M. (1978) Nighttime proton fluxes at Millstone Hill, Planet Spac Sci. 26:727-744.

15. Fritz, R. B. (1976) ATS-6 Radio Beacon Electron Content Measurements at Boulder, July 1974 — May 1975, Report-UAG 58, World Data Center A, September.

16. Fritz, R. B. (1978) Private communication, August 1978.

17. Soicher, H. (1978) Spatial correlation of transionospheric signal time delays, IEEE Transactions on Antennas and Propagation, AP-26(No. 2):311-314.

18. Davies, K., Degenhardt, W., Hartmann, G. K., and Leitinger, R. (1977) Electron Content Measurements Over the US, Joint Radio Beacon Program NOAA/MPA/GRAZ Station Report, ATS-6, 94°W., Edited by Max-Planck Institute for Aeronomie.